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Experimental investigation on effect of aluminium oxide nano-particles on hydraulic oil of HEMM lubricant

In this study, the effect of Al_2O_3 nano-particles on density and viscosity of hydraulic oil (Hydrex 100) used in heavy earth moving mining (HEMM) equipment is experimentally investigated. In base fluid (hydraulic oil) different volume fraction of Al_2O_3 (0.01%-1%) nano-particles are added. The present data show that with the increasing temperature the viscosity and density of base fluid and nano-fluid decreases, whereas it increases with increasing particle volume fraction. According to the experimental results of the viscosity, a new correlation for predicting the viscosity of nano-fluid with varying particle volume fraction has been presented.

Keywords: *dynamic viscosity, kinematic viscosity, density.*

Nomenclature

μ dynamic viscosity

ϕ particle volume fraction

I. Introduction

The primary function of a lubricant is to keep two metal surfaces apart, thus reducing friction and wear and also to remove excessive generated heat. Modern machinery with its constantly increasing speed and long duration of operations has added the performance demand for lubricants. Nano-lubricant, which is a suspension of nano sized particles in conventional lubricants, is one of the way to improve thermal and wear behaviour.

Kole and Dey [1] used copper oxide nano-particles (40nm) in gear oil and observed that three times increase in viscosity with 0.025 volume fraction of nano-particles. Particle aggregation was the main effect for such increment. Liu et al. [2] dispersed CuO nano-particles in synthetic oil and observed good friction reducing and anti wear properties. C S Jwo et al. [3] observed the increase in thermal conductivity of R-134a refrigerant lubricant with Al_2O_3 nano-particles increased by 4.6% and 2.5% with 1.5 and 2% wt. fraction respectively. Thus enhancement of thermal conductivity did not grow with increasing wt. fraction.

Prasher et al [4] observed that thermal performance get decreased with the increase in viscosity more than a factor of four relative to increase in thermal conductivity. K. Anoop et al [5] suspended SiO_2 nano-particles and observed the increment in viscosity value with increase in particle volume fraction and pressure. M A. Kedierski [6] suspended CuO nano-particles in synthetic polyester oil and proposed correlations for variation in viscosity and density of nano-lubricant with the suspension of nano-particles.

M. A. Kedierski [7] observed the conventional correlation for viscosity are not satisfactory predict the increase in viscosity of synthetic polyester – Al_2O_3 nano-lubricant.

In the present study hydraulic oil of HEMM (Hydrex 100) is used with aluminum oxide particles for forming nano-lubricant. Size distributions of particles, density and viscosity of nano-fluid have been investigated. A new correlation has been proposed on the basis of experimental value of viscosity.

II. Experimental procedure

In present work, aluminium oxide (Al_2O_3) nano-particles with volume fraction ranging between 0.1% to 1% 40 nm nominal diameter, density 3.965 g/cm^3 are dispersed into measured quantity of base hydraulic oil. Al_2O_3 particles are non metallic oxide and hence they would not react with base fluid. The size distribution of Al_2O_3 particles are obtained by nano zeta seizer. The instrument measures size distribution using DLS (dynamic light scattering) technique. This technique measures the diffusion of particles moving under Brownian motion and converts this to size distribution using the Stoke-Einstein relationship.

The mass of appropriate volume fraction is being accurately measured by electronic weighing machine with a least count of .001 mg. Since the base fluids are commercial lubricants, it is having some dispersant and hence no additional dispersant is added to the base lubricant. The required quantity base oil is made in batch of 100 ml at a time. After mixing of nano-particles in base lubricant, the

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suspension is homogenized for 1 hour by magnetic stirrer. The mixture agitated by ultrasonic shaker (Oscar ultrasonic) continuously for 2 hours to ensure uniform dispersion and good suspension stability. Finally batch wise sample is subjected to ultrasonic bath for 30 minute. Nano-lubricant thus prepared do not display any visual sedimentation of Al_2O_3 nano-particles, even after keeping the fluid stationary for more than thirty days. Before testing the properties of nano-lubricants have been subjected to additional 10 minute sonication for homogenising nano-fluid.

A Stabinger-type viscometer (Anton-Paar SVM 3000) was used to measure the dynamic viscosity and density of the nano-lubricant at four different temperatures between approximately 20°C to 50°C (10°C). The measurements were made at atmospheric pressure at an approximate altitude of 232 m above sea level (Dhanbad, "India"). The Stabinger measures viscosity by concentric cylinder method. Rheolab QC (Anton Paar) viscometer was also used to recheck the viscosity measured by Stabinger viscometer, and it was observed that both viscometers gave almost same results. The estimated maximum uncertainty in viscosity measured is within 3%.

III. Results and discussion

Ultraviolet visible spectro-photometer is used for finding out absorption and refractive index of nano-lubricant. Fig.1 shows the variation of absorption of UV light with varying wave length. The peak absorption is 3.233, obtained at 197.50 nm wave length. These parameters like absorption, wave length and refractive index is used in dynamic light scattering (DLS) measurement. DLS technique measures the diffusion of particles moving under Brownian motion and converts this to size distribution using the Stoke-Einstein relationship. DLS display average size of particles in nano-fluid is 219 nm as

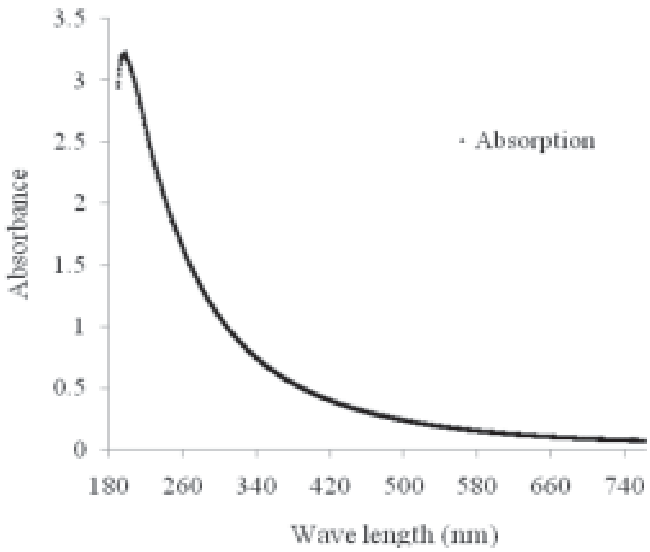

Fig.1 Ultraviolet-visible spectrophotometer of Al_2O_3 based nanolubricant

shown in Fig.2. This increase in particle size from original (40 nm) to 219 nm is due to the formation of agglomeration in the nano-lubricant.

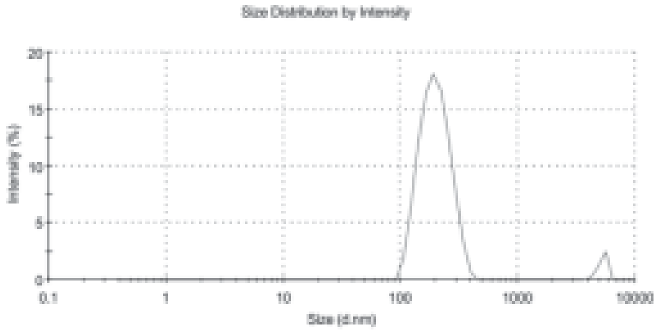

Fig.2 Representative particles size distribution

Fig.3 shows the variation of density of pure hydraulic oil and nano-lubricant with temperature at atmospheric pressure. It can be observed that the density increases with dispersion of Al_2O_3 particles whereas it decreases with increasing temperature for both pure hydraulic oil and nano-lubricant.

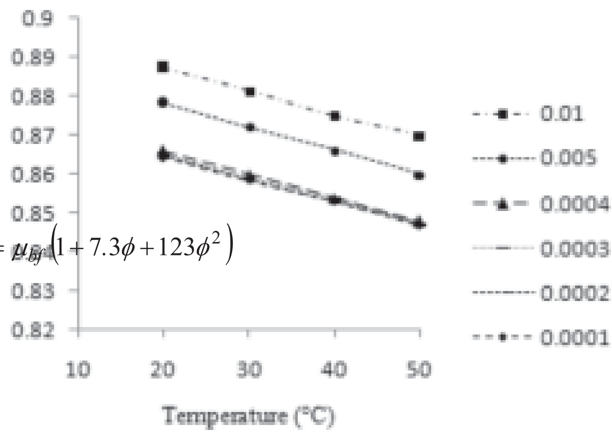

Fig.3 Variation of density of hydrex 100 based nano-lubricants at different operating temperature

The rheological properties of liquid suspensions have been studied since Einstein (1906) [8]. Einstein's equation can predict the effective viscosity of liquids in the low volume fraction having spherical suspended particles. The equation considers only the liquid- nano particle interaction and is valid for nano-particles volume concentration of less than 1.0%. Einstein formula of viscosity is expressed as [8]:

$$\mu_{nf} = \mu_{bf}(1 + 2.5\phi) \quad \text{... ...} \quad (1)$$

Furthermore, the viscosity of the nano-fluid is calculated using Wang's formula [9] which is expressed as:

$$\mu_{nf} = \mu_{bf}(1 + 7.3\phi + 123\phi^2) \quad \text{... ...} \quad (2)$$

The conventional theoretical relations are found to be largely inappropriate for predicting variation of viscosity with particle volume fraction. A new correlation has been correlating viscosity with particle volume fraction, which can be expressed as:

$$\frac{\mu_{nf}}{\mu_{bf}} = 42.67168\phi^2 - 1.3797\phi + 1 \quad \dots \quad (3)$$

The residual (R) value is 0.9957 and volume fraction is in percentage.

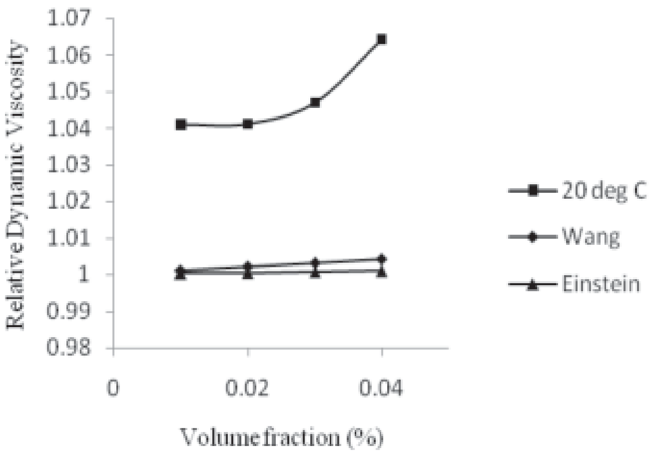

Fig.4 Relative dynamic viscosity variation of Al_2O_3-hydrex 100 based nano-lubricants

Fig.5 show that the variation of kinematic viscosity of Al_2O_3-Hydrex 100 based nano-lubricants. From the plot we can see that by increasing temperature the kinematic viscosity of the nano-lubricant is decreases. We can also see that with the change of increasing volume fraction of Al_2O_3 nano-particles the kinematic viscosity of the corresponding oil is subsequently slightly increasing.

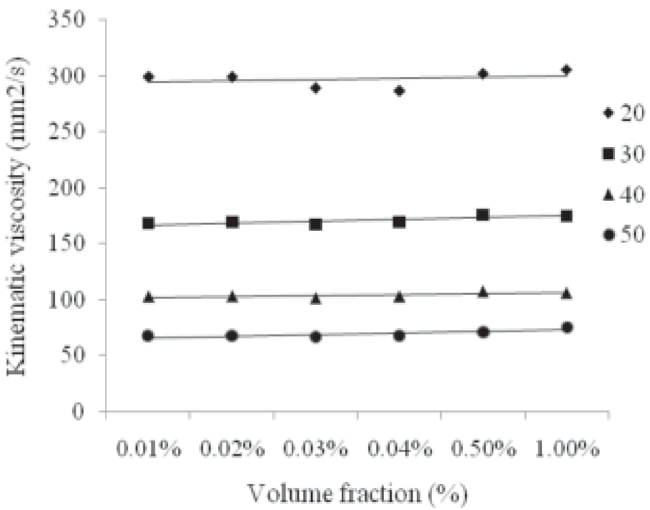

Fig.5 Kinematic viscosity variation with increasing aluminum nanoparticle volume fraction

IV. Conclusion

The variation of viscosity, density and of HEMM hydraulic oil (Hydrex 100) with the addition of Al_2O_3 particles is experimentally investigated. The presence of agglomerated particle has been revealed by DLS image. Density and viscosity of nano-lubricant increases with increasing Al_2O_3 particles volume fraction. Classical models for theoretically prediction of viscosity of nano-fluid has found largely inappropriate for prediction of viscosity variation. Hence, a new correlation for variation of dynamic viscosity of hydraulic oil with the addition Al_2O_3 nano-particles has been proposed.

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